25 copies

NASA TECHNICAL MEMORANDUM

NASA TM X-52436

GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 3.00

Microfiche (MF) .65

ff 653 July 65

NASA TM X-52436

FACILITY FORM 602

N68-31095 (ACCESSION NUMBER)	(THRU)
7 (PAGES)	1 (CODE)
(NASA CR OR TMX OR AD NUMBER)	03 (CATEGORY)

STATUS OF THE CADMIUM SULFIDE THIN-FILM SOLAR CELL

by F. A. Shirland
Clevite Corporation
Cleveland, Ohio

and

A. F. Forestieri and A. E. Spakowski
Lewis Research Center
Cleveland, Ohio

TECHNICAL PAPER proposed for presentation at Intersociety Energy Conversion Engineering Conference sponsored by the Institute of Electrical and Electronics Engineers
Boulder, Colorado, August 14-16, 1968

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION · WASHINGTON, D.C. · 1968

STATUS OF THE CADMIUM SULFIDE THIN-FILM SOLAR CELL

by F. A. Shirland

Clevite Corporation
Cleveland, Ohio

and

A. F. Forestieri and A. E. Spakowski

Lewis Research Center
Cleveland, Ohio

TECHNICAL PAPER proposed for presentation at

Intersociety Energy Conversion Engineering Conference
sponsored by the Institute of Electrical and Electronics Engineers
Boulder, Colorado, August 14-16, 1968

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

STATUS OF THE CADMIUM SULFIDE THIN-FILM SOLAR CELL

by F. A. Shirland
Clevite Corporation
Cleveland, Ohio

and A. F. Forestieri and A. E. Spakowski
Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio

E-4449

ABSTRACT

The CdS thin-film solar cell has major advantages for space power applications because of its large size, lightweight, flexibility, radiation resistance and low cost potential. The cells are not yet acceptable, however, because of degradation and instabilities incurred under thermal cycling at simulated space conditions.

A brief description is given of the design of the cadmium sulfide thin-film solar cell as it has evolved to date for space applications. The performance levels achieved are summarized along with the degree of reproducibility and yields obtained on pilot production in recent months. Improvements in design and performance presently being investigated are also discussed.

A summary of the results of testing of cadmium sulfide thin-film solar cells is presented. These include cells subjected to the following conditions: wet shelf storage, dry shelf storage, vacuum thermal storage, and vacuum thermal cycling.

INTRODUCTION

Early design CdS thin-film solar cells were unstable on shelf storage and were very susceptible to moisture degradation from high humidity ambients. (1) Later design cells appear to be stable on shelf storage and relatively unaffected by moisture. However, they have had very erratic performance behavior when exposed to alternating periods of high and low temperatures such as would occur in a near-Earth orbit. In this paper the progress and characteristics of the present CdS film cell are summarized and the results of various stability tests presented. In particular, cell performance under thermal cycling is emphasized. Detailed analyses and discussion of all the results can be found elsewhere. (2)

Cell Design

The CdS thin-film solar cell construction is shown in Fig. 1. The cell is a multilayered structure. The CdS layer is a polycrystalline film, one surface of which is converted to Cu_2S. Light is absorbed in the Cu_2S, and charge separation occurs in an insulating region between the p-type Cu_2S and the n-type CdS. The negative electrode is a silver coating on the plastic film substrate which extends the full width of the cell from one end to form the negative lead. The positive electrode is a fine metal screen attached to the Cu_2S with a conductive epoxy cement. A full-width extension of this grid from the opposite end of the cell forms the positive lead. The package is completed with a cemented front cover plastic. The cell is 4 mils thick and a standard size of 3 by 3 inches with an active area of 55 cm^2 has been developed.

Performance and Reproducibility

The plastic substrate cell is very flexible and can be bent readily over a radius as small as 1/4 inch without apparent damage. A cell of 55 cm^2 active area weighs less than 1.75 grams. These cells have been found to be virtually unaffected by high-energy particle radiation.(3,4) These particles included electrons between 0.6 and 2.5 MeV and protons between 2 and 10 MeV.

With Mylar as the front cover plastic, recent cells have averaged between 5 and 6 percent conversion efficiency at 25° C in air mass one (AM1) sunlight. However, for use in space for periods longer than about 6 months the uv content of sunlight causes the Mylar to darken and become brittle. (5) Kapton is more stable in the space environment, although it causes the cell efficiency to be reduced by 20 percent when used as a cover plastic because of its poor transmission of blue light. At air mass zero (AM0), cell efficiency is reduced by about an additional 15 percent. A cell with efficiency of 6 percent AM1 $\times$ 0.8 $\times$ 0.85 = 4.1 percent AM0 performance showing the 20 and 15 percent losses due to the Kapton and spectral shift, respectively.

Fig. 2 shows the distribution of cell efficiencies experienced recently for Kapton covered cells at 25° C AM0 test conditions. The distribution peaks at an efficiency of 3.4 percent. Over 75 percent of the cells produced in this time period are within 10 percent of the peak value.

Yields of CdS thin-film solar cells on a pilot line have been reasonable even at times of wide fluctuations of raw material and component part quality and during periods of experimentation with the processing equipment and conditions. Over a year's time when difficulties and

TM X-52436

experiments were at an all-time high, yields averaged about 40 good cells per 100 CdS film starts. During shorter periods of better process control, yields of 85 to 90 percent have been experienced. There is a good indication that these yields can be achieved in production.

Stability - Shelf Storage

Earlier design CdS film cells were unstable on shelf storage because the grids which were held down by pressure contact gradually loosened. Also, the Nylon adhesive used to laminate the front cover was hygroscopic and absorbed moisture. When a conductive epoxy cement was used to attach the grids, and a clear epoxy cement was used to attach the cover plastic, the cells became quite stable on dry shelf storage and relatively unaffected by humid atmospheres.

Fig. 3 shows the average relative power output for a group of 18 cells of the present design that have been on dry shelf storage for 14 to 19 months. Most of these cells are showing no loss of output. However, some of them have degraded quite badly and this accounts for the downward trend in the curve. In these cases faulty processing was known to be at fault. Also shown in Fig. 3 are the data for a group of 20 of the present design cells which have been on 80 percent relative humidity shelf storage for 12 to 18 months. There is a slight but definite degradation of output of most of these cells, averaging 9 percent per year. However, the degradation due to moisture is recoverable by drying the cells.

High Temperature Storage

Each month a group of standard-process cells has been placed in a vacuum oven maintained at 100^{o} C and then removed for output testing at regular intervals under standard conditions. Some cells have failed on this test after a few months, but a few cells have shown a slow steady loss of output suggestive of a diffusion mechanism. The I-V characteristics of these cells show a steady loss of fill factor due to an increasing series resistance.

Fig. 4 shows the relative power output of the 4 best cells on this test after correction to remove fluctuations due to the inaccuracy of measurement. This group of cells degraded by 10 percent on the average after the first 8 months of 100^{o} C exposure.

Other cells placed on 150^{o} C vacuum storage degraded much faster, as would be expected. The results were very erratic, but the 4 best cells of the group lost about 10 percent of their output in 4 weeks at 150^{o} C. Again the loss was characterized by increasing series resistance.

A preliminary exponential extrapolation of these data to the condition of 60^{o} C storage, which is an expected temperature of operation in a near-Earth orbit, indicates a minimum lifetime of 5 years at 60^{o} C before a loss of 10 percent of cell output would be expected. A calculated curve for this condition is presented in Fig. 4. The concept of a continuing diffusion process which increases the thickness of the insulating region is corroborated by a decrease in junction capacitance and an increase in the reverse breakdown voltage with time at temperature.

Thermal Cycling

The most important test for a solar cell is how well it will perform under the same conditions in which it will be used. For space applications these include high vacuum, ultraviolet radiation and wide temperature fluctuations. In most of the present thermal cycling tests, cycles corresponding to Earth orbital times of 90 minutes or longer are used.

In Fig. 5 the thermal cycling results for cells fabricated in October 1967 are shown. In the tests conducted at the Boeing Company[6] the cells were cycled from $+63^{o}$ C to -128^{o} C in a vacuum below 10^{-6} torr. The cells were illuminated by a xenon light solar simulator for 1 hour followed by darkness for another hour. The test conditions at NASA Lewis were $+41^{o}$ C to -70^{o} C and 10^{-7} torr. A similar solar simulator was used and the cycles consisted of 1 hour of light and 1/2 hour darkness. The upper two curves represent the most stable cells in both tests. In the NASA test after 208 thermal cycles, the cells were brought to ambient conditions for one day and then tested for an additional 100 cycles. As a result of the test interruption at cycle 208, the cells showed some recovery from the degradation. The best cell went from 88 to 93 percent of its initial maximum power and the other cells went from 63 to 85 percent of their average initial maximum power. At the conclusion of the tests the cells were removed from the vacuum chamber and their performance was measured under standard conditions. The cells recovered to an average of 95 percent of their original maximum power as measured under identical conditions before the start of the tests.

In Fig. 6 the results of thermal cycling tests of cells fabricated in December 1967 are shown. In the tests conducted at Lincoln Laboratory[7] the cells were cycled from $+76^{o}$ C to -86^{o} C at 10^{-6} torr using a $1\frac{1}{2}$ hour light, $1\frac{1}{2}$ hour dark cycle. Standard tungsten lamps were used to illuminate the cells during the light cycle. At NASA the test conditions were similar to those in the previous test: $+50^{o}$ C to -120^{o} C, 10^{-7} torr, 1 hour light, 1/2 hour darkness. Here again the results are separated to indicate best cell performance and other cell performance. At cycle 180, the NASA tests were interrupted and the cells were brought to ambient conditions for one day before continuing the tests. Again a partial recovery was noted at the interruption. The best cell went from 86 to 99 percent of its initial maximum power and the other cells went from 77 to 96 percent of their average initial maximum power.

CONCLUSIONS

The CdS thin-film solar cells have continued to improve with regards to stability. The cells are stable on shelf storage and undergo some degradation under thermal cycling. The instabilities found to date are believed to be due to mechanical faults in the construction of the cell and not to intrinsic cell changes. The degradation noted under thermal cycling consists of both a recoverable and nonrecoverable part. The larger recoverable part is believed to be related to the mechanical faults. The cause for the nonrecoverable part is still unknown.

There are several possibilities for improving the output level of the cells. These are replacing the Kapton cover plastic with more transparent materials, reducing the sheet resistance of the conductive substrate layer, increasing the transmission of the positive electrode grid, and closer control of processing parameters to reduce the incidence of lower-output cells. An increase in the average AM0 25^{o} C outputs to at least the 5 to 6 percent level may be realizable with continued development.

Thinner, lighter weight cells and cells of larger area should also be realizable with further development work. The cell thickness can probably be reduced to just over half the present thickness, and the cell size can probably be increased to about 4 to 5 times the present size.

REFERENCES

1. A. E. Spakowski and J. G. Ewashinka, "Thermal Cycling of Thin-Film Cadmium Sulfide Solar Cells," NASA TN D-3556, 1966.

2. F. A. Shirland, W. K. Bower, and J. R. Green, "CdS Solar Cell Development," Clevite Corporation, NASA CR-72382, Feb. 29, 1968.

3. Private communications from J. J. Loferski, Brown University.

4. Unpublished data by H. W. Brandhorst, NASA Lewis Research Center.

5. E. Anagnostou, "Effect of Ultraviolet Irradiation on Selected Plastic Films in Vacuum," NASA TM X-1124, 1965.

6. A. G. Stanley, "Present Status of Cadmium Sulfide Thin-Film Solar Cells," Lincoln Laboratory, Tech. Note 1967-52, Dec. 13, 1967.

7. Private communication from A. G. Stanley, Lincoln Laboratory.

E-4449

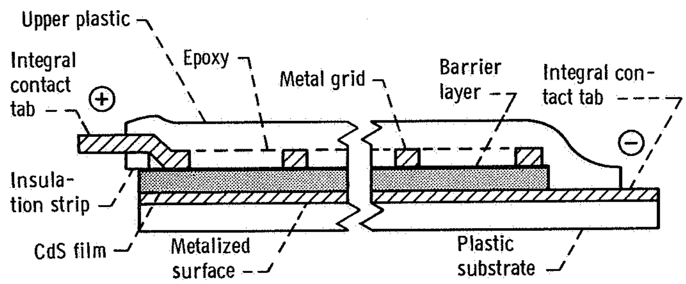

Figure 1. - Cross-section of CdS thin film solar cell.

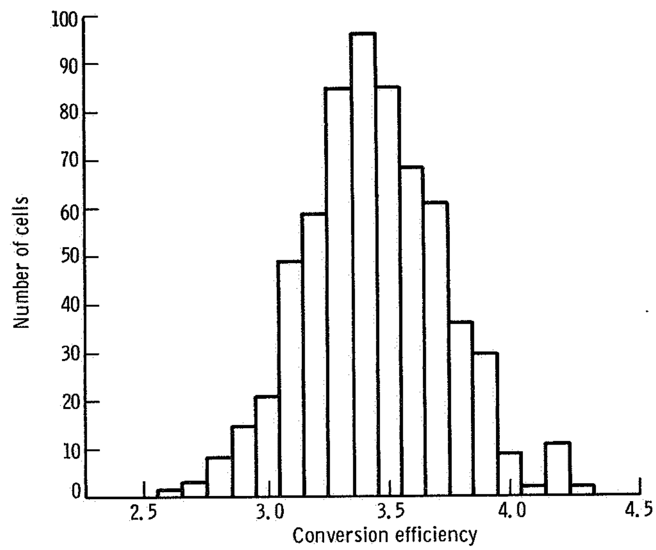

Figure 2. - Distribution of conversion efficiencies for standard 3" x 3" Kapton covered CdS solar cells, August 1967 through February 1968, measured at 25° C air mass zero.

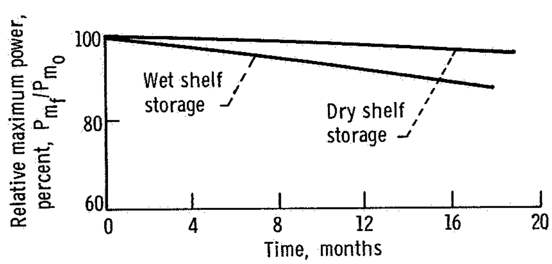

Figure 3. - Effect of dry and wet shelf storage on power output of CdS solar cells.

E-4449

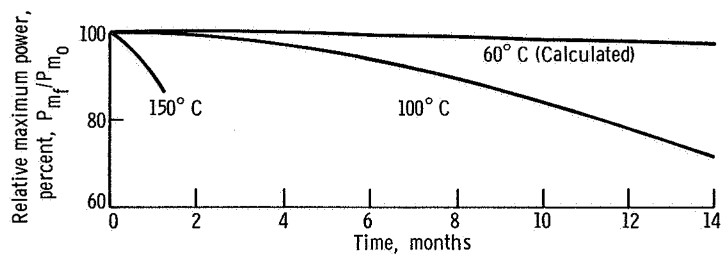

Figure 4. - Effect of thermal vacuum storage on power output of best CdS solar cells.

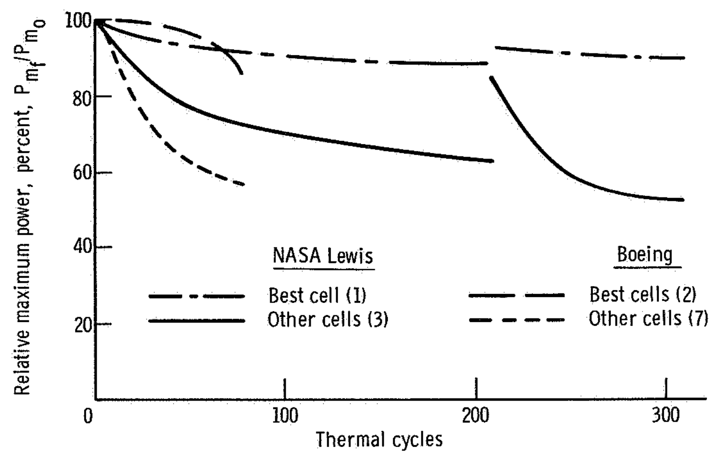

Figure 5. - Effect of thermal cycling on power output of October 1967 CdS solar cells.

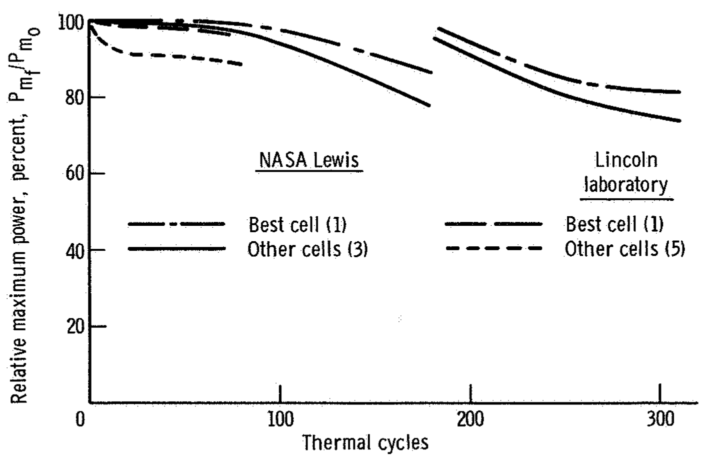

Figure 6. - Effect of thermal cycling on power output of December 1967 CdS solar cells.